Wind Flow Modeling

- Why do we need wind flow modeling?

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- Because we don’t have measurements at every potential turbine location.
- Wind flow modeling is relatively uncertain.

- The handbook does not prefer one method over another.

- There are four categories of wind flow models.

Types of Wind Flow Models

- Conceptual models
- Experimental models
- Statistical models
- Numerical wind flow models

Conceptual models

- A good conceptual understanding of wind flow is valuable in all spatial modeling.
- What are some examples of conceptual models?

Conceptual models

- The influence of elevation on mean wind speed.
- Winds on upwind slopes versus downwind slopes.
- Channeling through mountain gaps.
- Impact of trees and other vegetation.

Experimental models

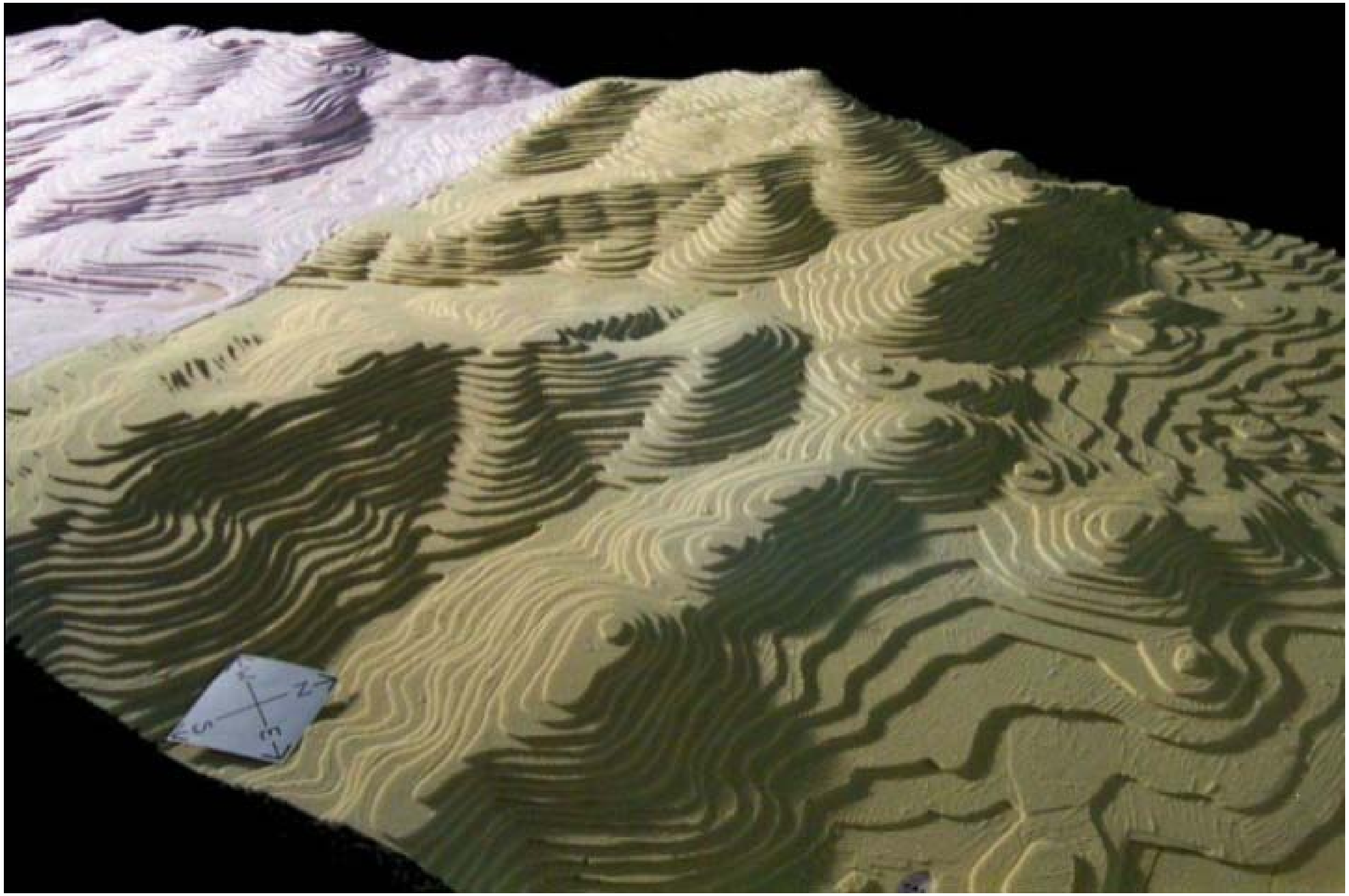


Figure 13-1 Scale model of Altamont Pass used in wind tunnel tests. (Source: Lubitz, W.D. and R.B White, "Prediction of Wind Power Production Using Wind-Tunnel Data, a Component of a Wind Power Forecasting System"

- What are the potential benefits and problems with this approach?

- Wind tunnel speed and turbulence must be matched to the scale of the model to replicate real conditions.
- Takes time and skill to build such a model.
- Difficult to reproduce some conditions, such as thermally stable conditions.

Statistical models

- Based entirely or mostly from on-site wind measurements.
- Use several predictive parameters to find those that have the strongest relationship with the wind observations at several masts.

- What parameters might one use?

- Use parameters for which there is a reasonable physical basis for believing a relationship should exist.
- A good conceptual model is valuable.

- Some parameters that might be considered:
  - Elevation
  - Slope
  - Exposure
  - Surface roughness

- Statistical models are grounded in measurement, fairly simple, and transparent.
- Can work very well, especially for wind climates driven by synoptic-scale winds (i.e., when thermally driven mesoscale circulations are absent).
- Strong relationships between speed and topography occur in these situations.

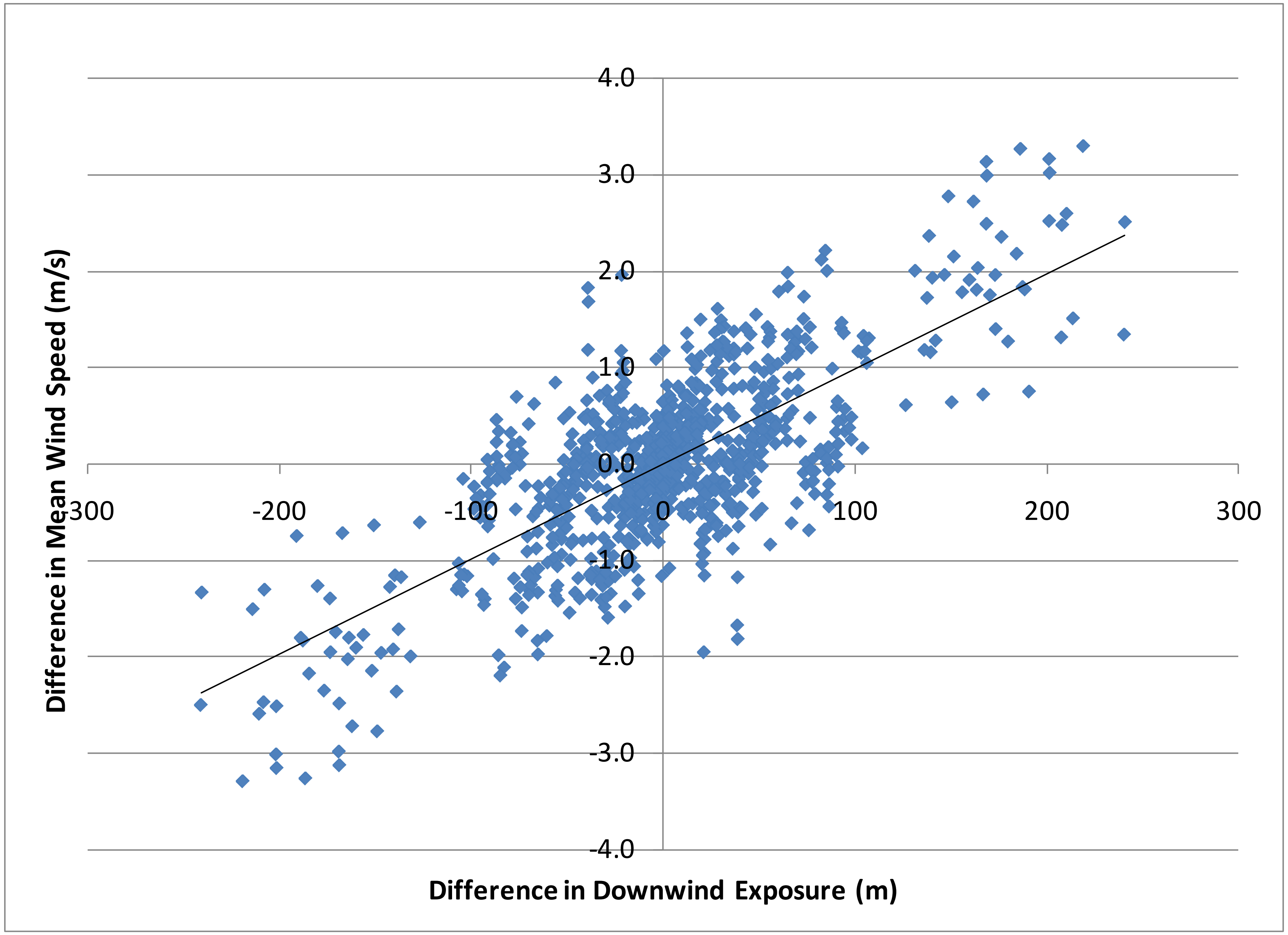


Figure 13-2 Data from pairs of 74 towers in seven wind resource areas indicate a significant relationship between the differences in mean speed and downwind exposure. Such a statistical relationship can be used to predict variations in wind speed across a project area. (Source: AWS Truepower)

- A problem with statistical models is potentially large errors when results are extrapolated outside the range of conditions used to develop (or train) the model.

- Determining the accuracy can also be challenging.
- Usual method is to withhold some data from the training set to use for validation.
- Statistical models can be combined with other wind flow modeling approaches, such as numerical flow models.

Numerical flow models

- Mass-consistent
- Jackson-Hunt (small hill)
- computation fluid dynamics (CFD)
- mesoscale NWP

Mass-Consistent Models

- First generation of wind flow models (1970s and 1980s)
- Solve just one of the physical equations governing fluid flow: Mass conservation.
- Stronger winds on hills and ridges.
- Cannot handle thermally driven winds or flow separation in lee of hills.

- Solution is not unique so constraints must be added, such as a first-guess field or measurements from towers.

Jackson-Hunt Models

- Next generation: 1980s and 1990s.
- Based on theory of Jackson and Hunt (1975).
- Model assumes that terrain causes a small perturbation to a constant background flow.

- **WAsP** is a J-H model developed at Riso Nat'l Lab. of Denmark.

- Still is most widely used numerical wind flow model.

- Especially popular in Europe.

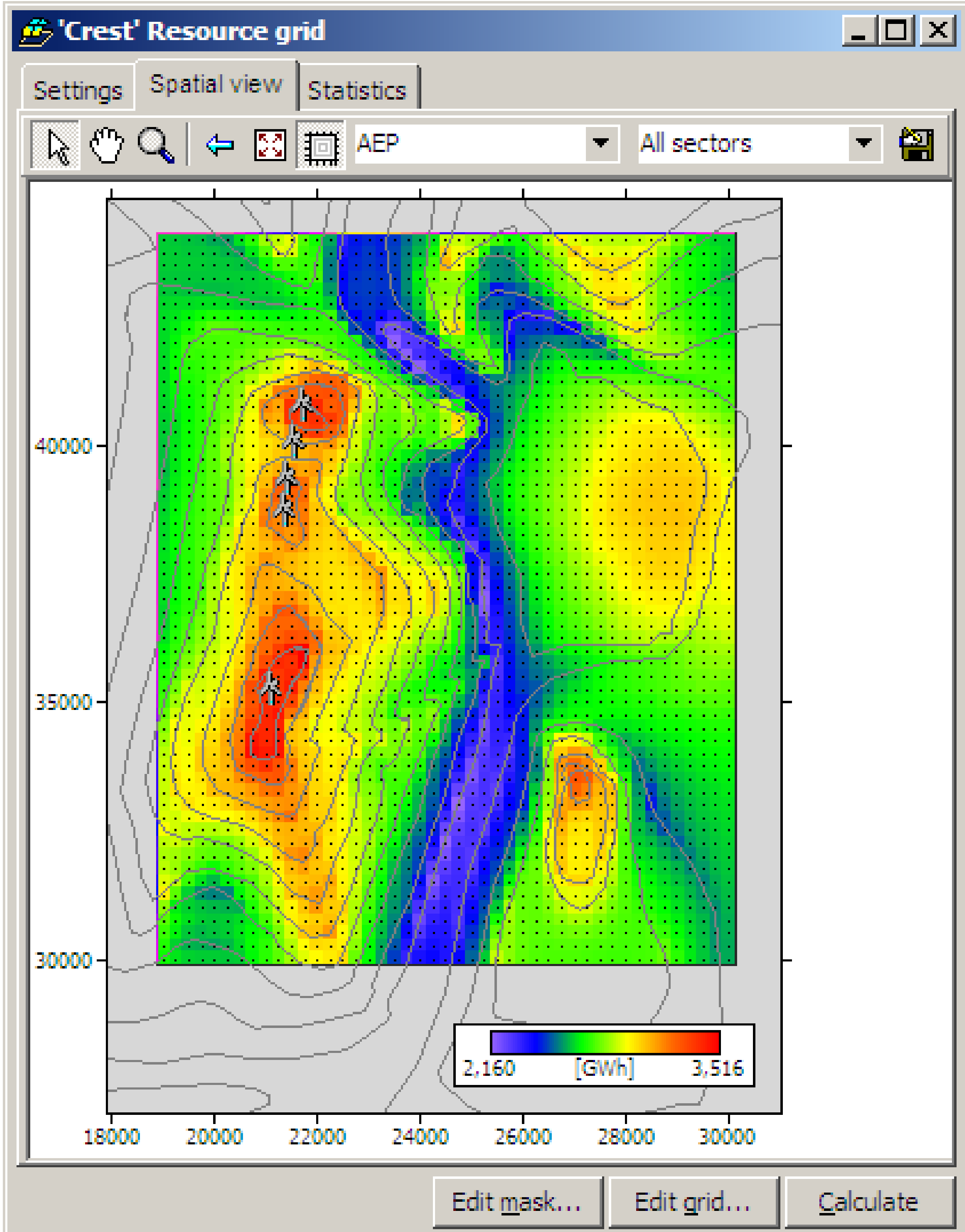


Figure 13-3 WAsP, depicted here, is a popular wind flow modeling application. Like other Jackson-Hunt models as well as mass-consistent models, WAsP captures the tendency of wind speed to increase over high ground and decrease in valleys. Ridges oriented perpendicular to the flow exhibit the greatest topographic acceleration.

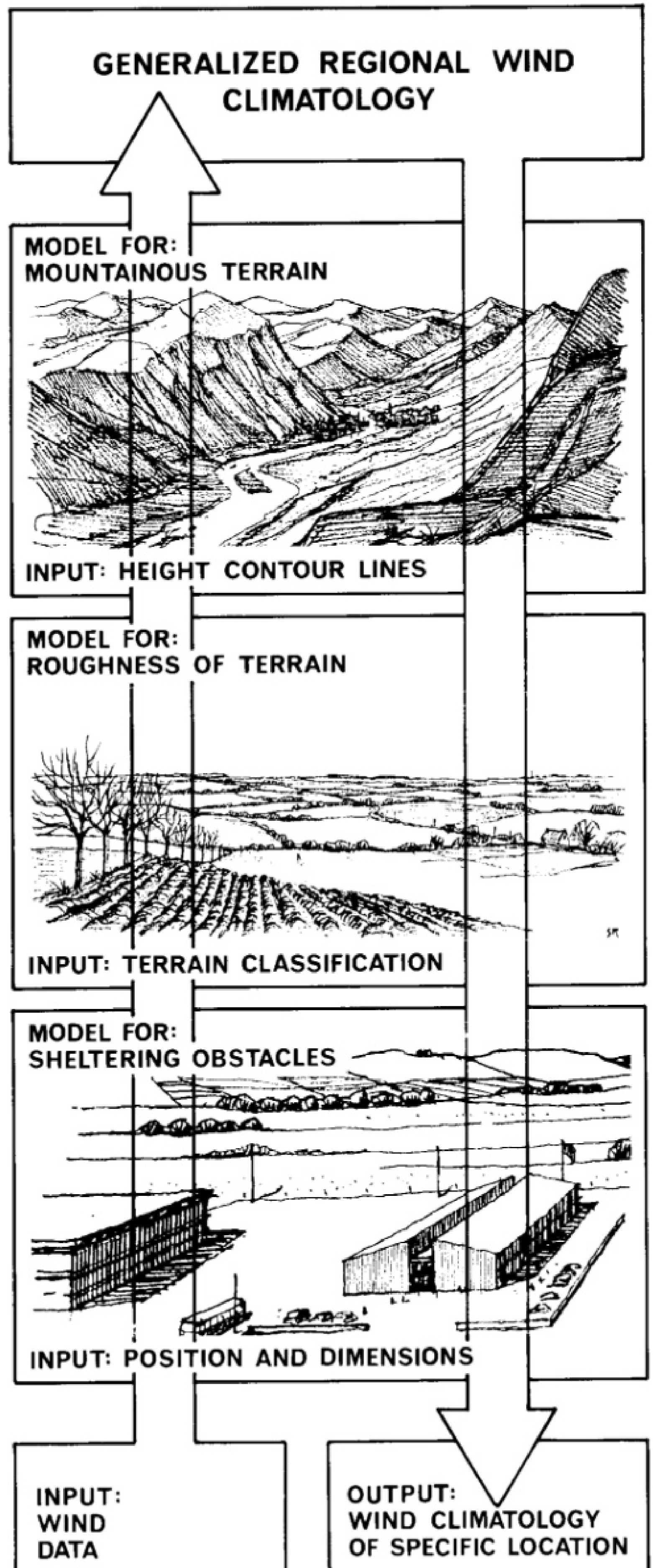


Figure 13-4 The WAsP mapping process.

CFD Models

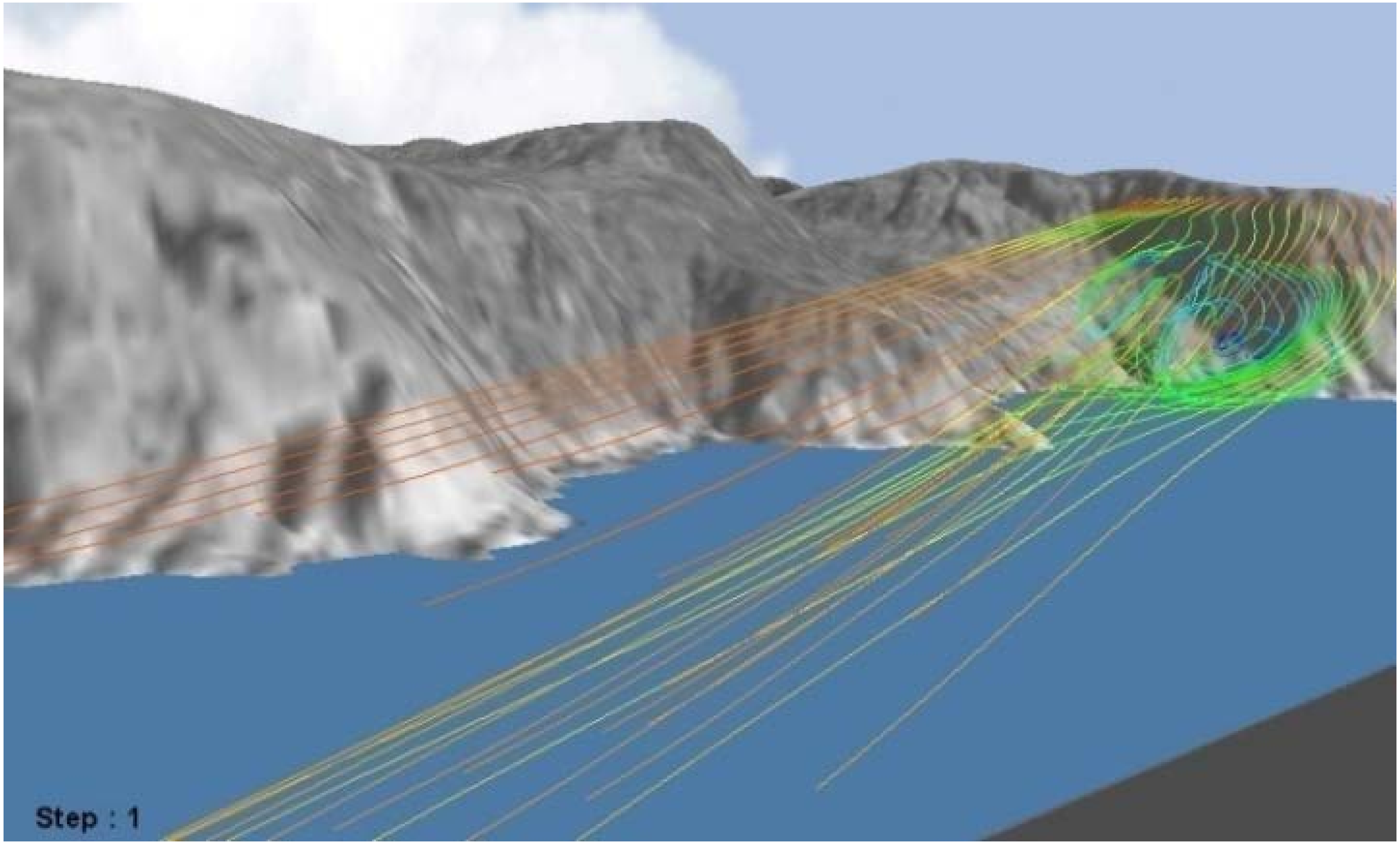
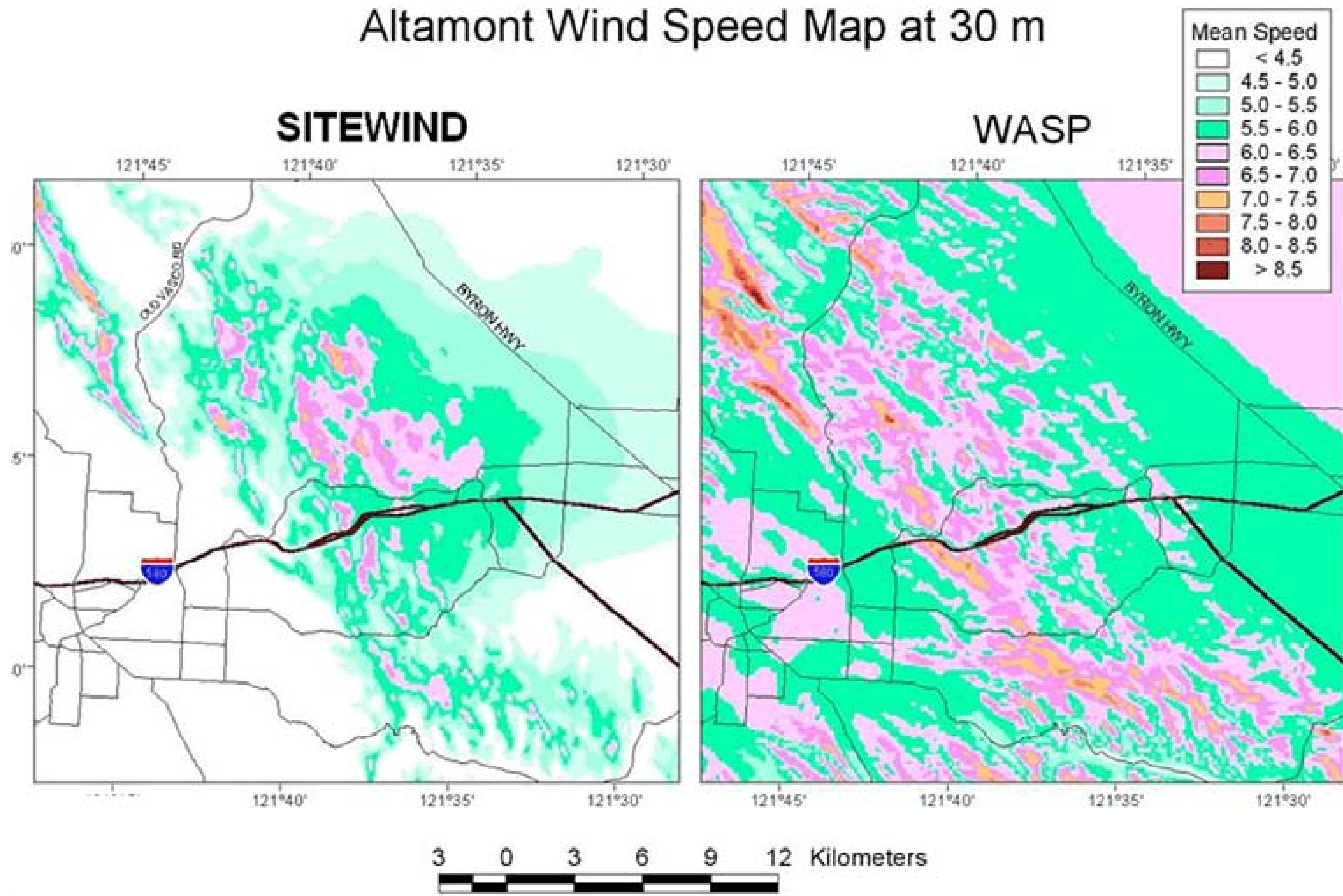


Figure 13-5 CFD models like WindSim, depicted here, are capable of simulating non-linear flow features as recirculation behind steep terrain. (Source: WindSim)

Mesoscale NWP Models



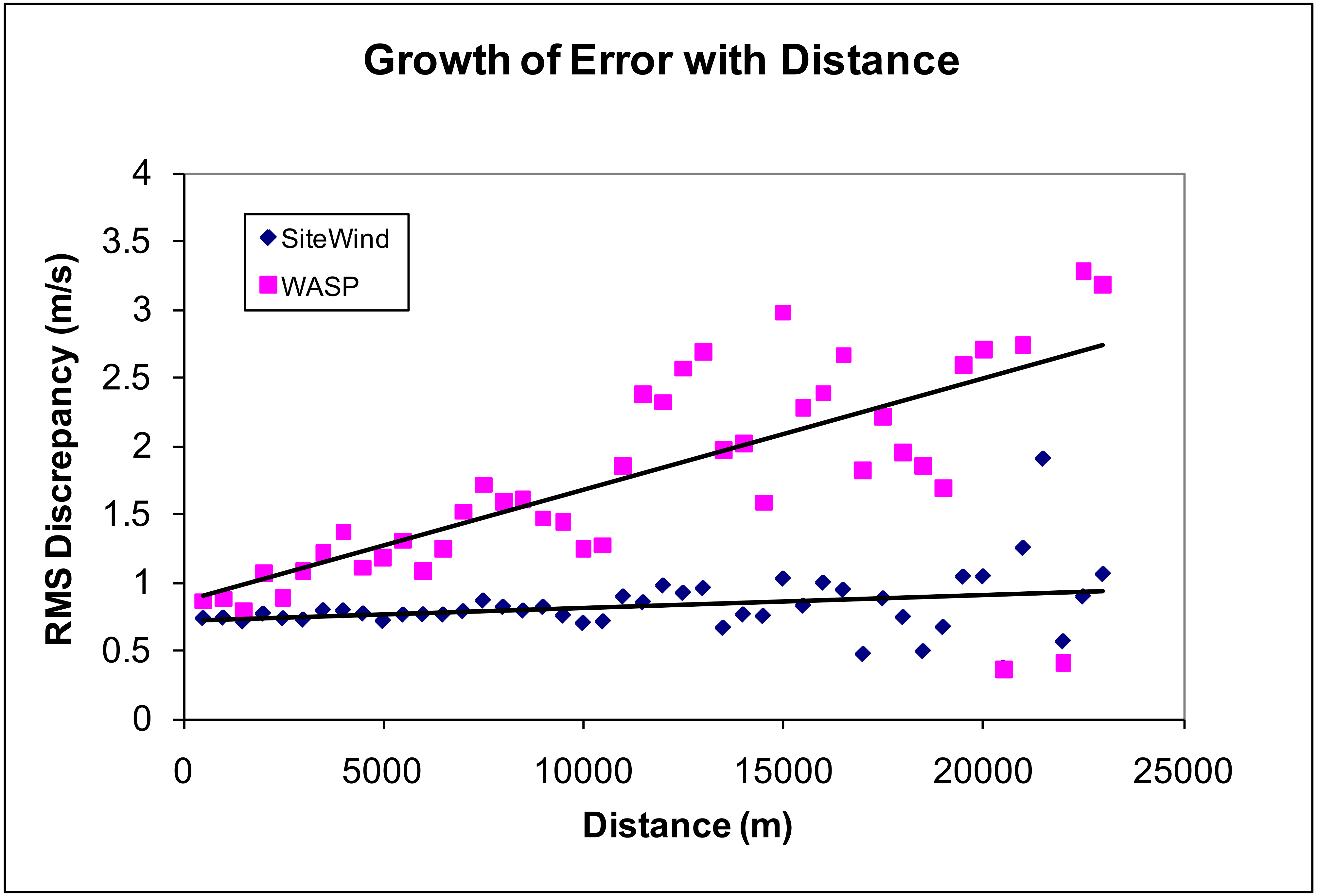


Figure 13-6 ***Top***: **Wind resource maps created by the SiteWind mesoscale-microscale modeling (top, left) system and by WAsP (top, right). The SiteWind map shows the wind resource concentrated on the eastern slopes approaching Byron Highway, the result of gravity acting on relatively cool, dense marine air. WAsP suggests the wind resource is more widely distributed and is at a maximum at the top of the pass.** ***Bottom***: **Comparison with observations indicates the SiteWind analysis is more correct. [49])**